Blasting

Some definitions: explosives technology

- **Deflagration**
  fast chemical burning Reaction => burning < 600 m/s
- **Detonation:**
  - An exothermic chemical reaction
  - associated with a supersonic shock wave.
  The reaction is started by heat resulting from compression by the shock wave.
  => 2000 ….. < 6000 m/s
  Energy from the reaction sustains the shock wave.
- **Explosion:** “ A rapid expansion of matter to a volume much greater than its original volume ”
- **Explosives:** - Substances that rapidly liberate their chemical energy as heat, to
  - form gaseous products (and perhaps solids too)
  - and generate high temperatures and pressures.

Blasting

History

Overhead 7.3

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- **1260:** Gunpowder formula recorded (earlier use: China)
- **1831:** Safety fuse invented by Bickford
- **1846:** Nitrocellulose prepared by Sonbein (discovered earlier - between 1833 -1846, but was unstable)
- **1847:** Nitroglycerine discovered by Sobrero
- **1863:** TNT discovered by Wilbrand
- **1865:** Mercury fulminate detonator introduced by Alfred Nobel (Another source mentions 1867)
- **1866:** Dynamite invented by Alfred Nobel
- **1867:** Ammonium nitrate introduced into dynamite to replace some of the nitroglycerine
- **1875:** Blasting gelatine invented by Alfred Nobel
- **1879:** Tetryl discovered by Michler and Meyer
- **1910:** Delay detonators (piece of safety fuse) introduced

Blasting

History

Overhead 7.4

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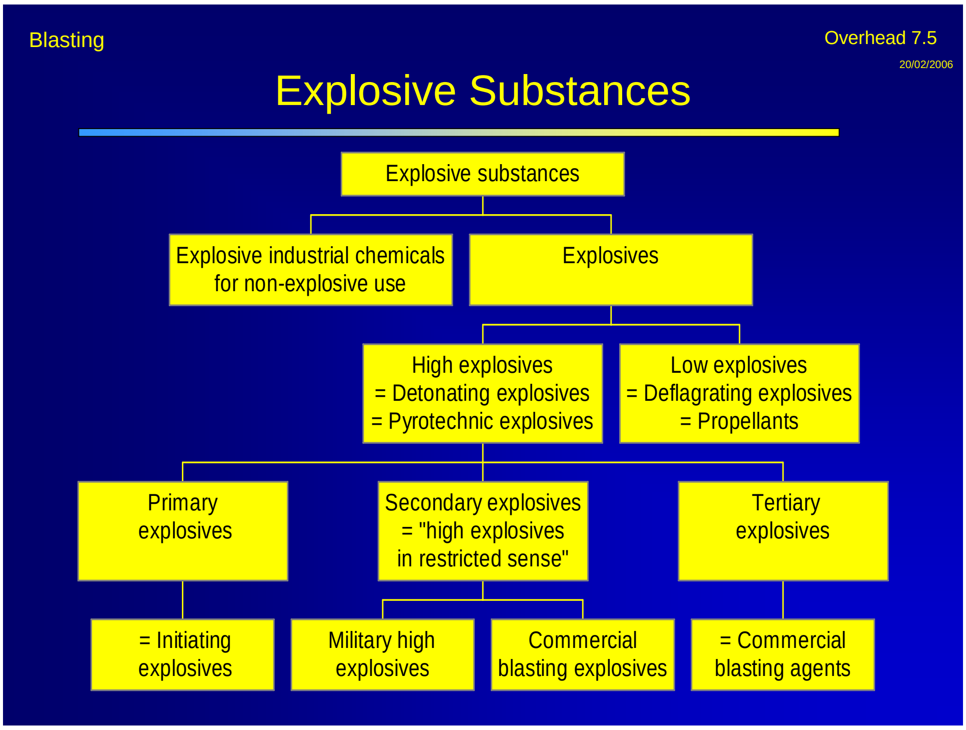
- **Before 1930:** "Cordeau" (TNT in a Pb tube): a safe fore-runner of detonating cord; earlier attempts dangerous)
- **1930:** Modern detonating cord introduced: PETN based
- **1935:** "Nitramon" introduced: sensitized ammonium nitrate in metal cans (to keep dry)
- **1940:** Research on water-gel explosives started
- **1955:** Mixture of fertilizer grade ammonium nitrate and solid fuel was patented by Lee and Akre
- **1958:** Commercial introduction of water-gel explosives
- **1967:** "Nonel" shock-tubes patented
- **1967:** Emulsion explosive first patented by Bluhm
- **1969:** MMAN patented: cap-sensitive water-gels possible
- **1977:** Cap-sensitive emulsion explosive patented: Wade
- **1979:** „Magnadet" detonators patented: Jones & Mitchell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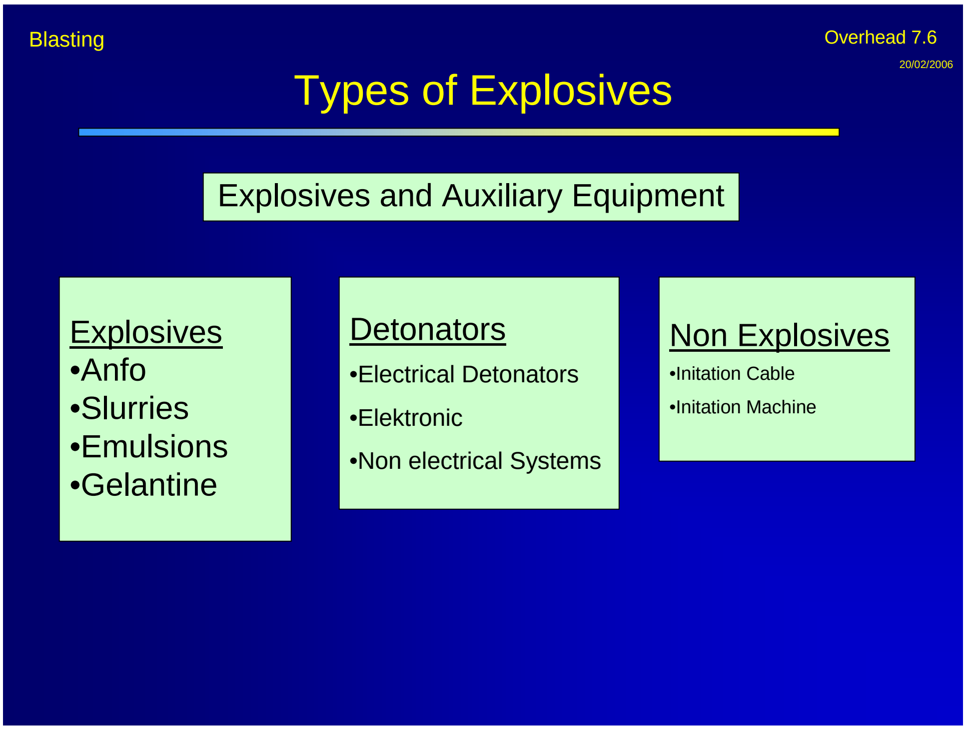
Explosive Substances
Explosive substances
Explosive industrial chemicals for non-explosive use
Explosives
High explosives = Detonating explosives = Pyrotechnic explosives
Low explosives = Deflagrating explosives = Propellants
Primary explosives
Secondary explosives = "high explosives in restricted sense"
Tertiary explosives
= Initiating explosives
Military high explosives
Commercial blasting explosives
= Commercial blasting agents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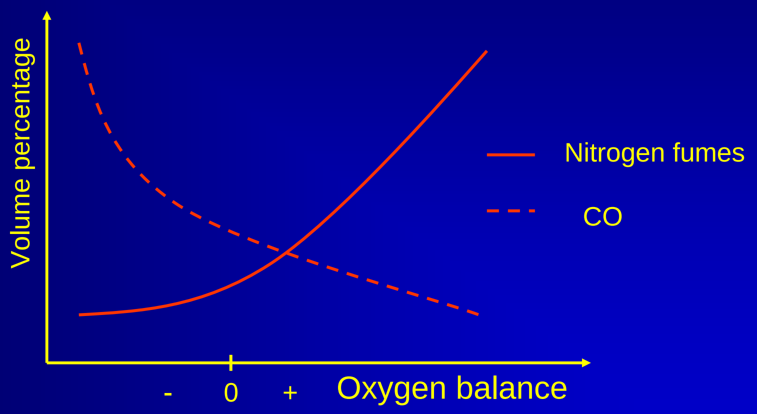
Types of Explosives
Explosives and Auxiliary Equipment
Explosives
•Anfo
•Slurries
•Emulsions
•Gelantine
Detonators
•Electrical Detonators
•Elektronic
•Non electrical Systems
Non Explosives
•Initation Cable
•Initation Machine

Definitions

- **Oxygen balanced**
  - Positive %
  - Negative %
- **Velocity of Detonation (VOD)**
  - Related to energy release
  - Depends on: charge diameter, confinement, density, particle size

Explosive Fumes



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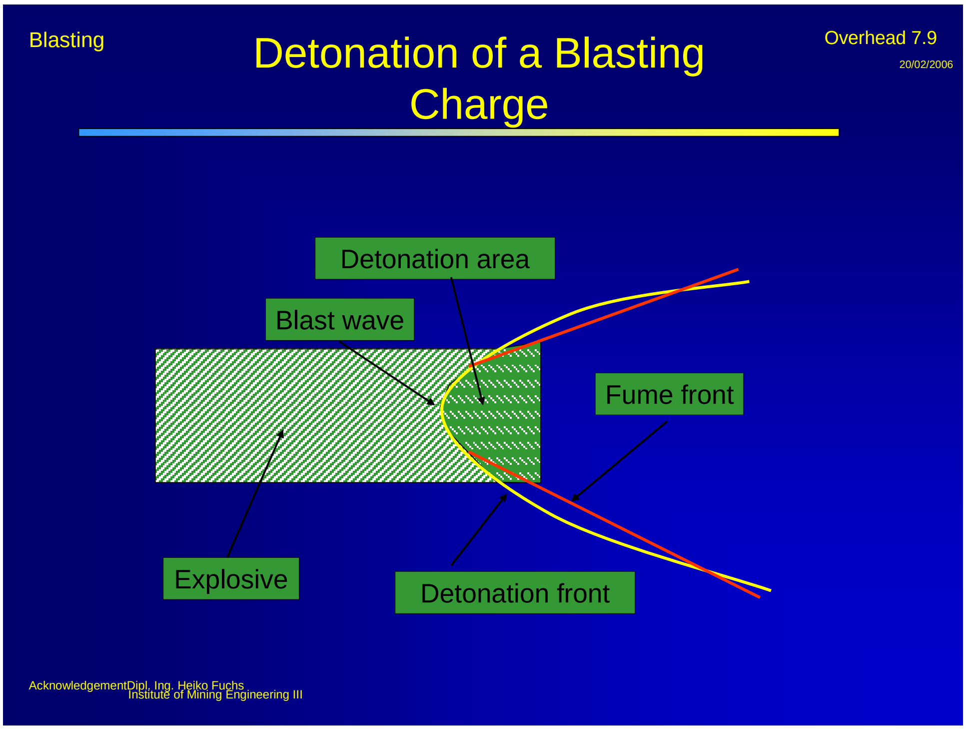

Blasting
Detonation of a Blasting Charge
Overhead 7.9
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Detonation area
Blast wave
Fume front
Explosive
Detonation front
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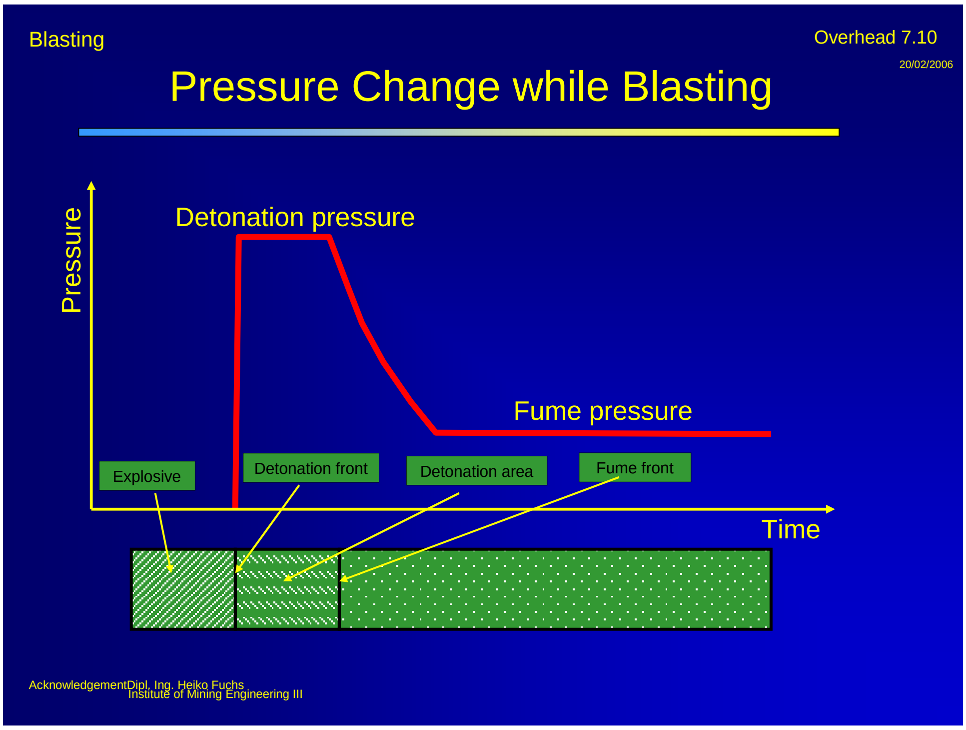

Blasting
Pressure Change while Blasting
Overhead 7.10
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Pressure
Detonation pressure
Fume pressure
Explosive
Detonation front
Detonation area
Fume front
Time
AcknowledgementDipl. Ing. Heiko Fuchs
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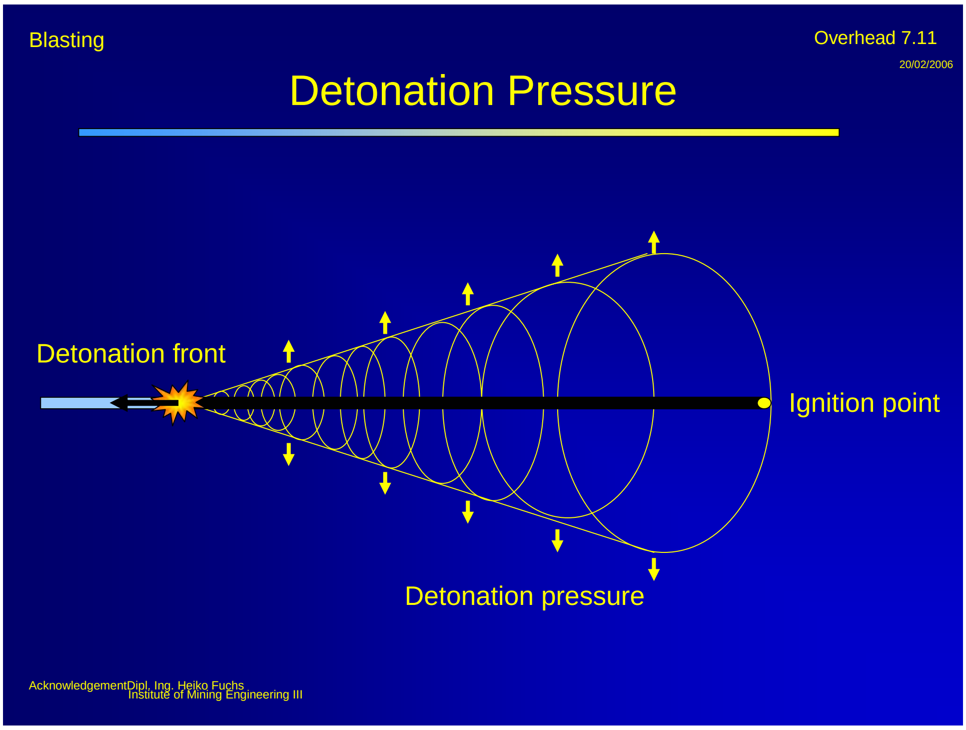
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Detonation Pressure
Detonation front
Ignition point
Detonation pressure
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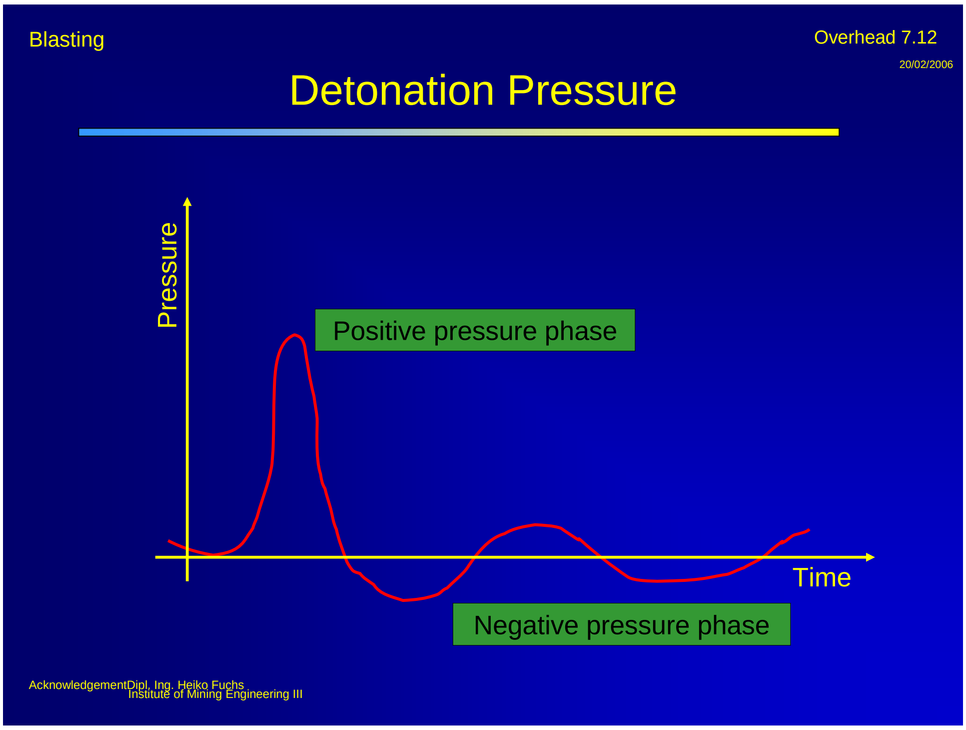
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Detonation Pressure
Pressure
Positive pressure phase
Time
Negative pressure phase
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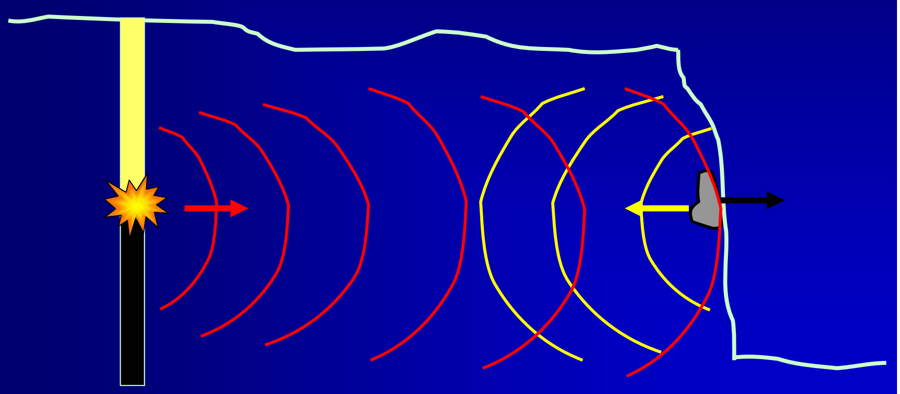
Progression of Shock Waves



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Explosives

- **Initiating (primary) explosives**
  - Mercury Fulminate
  - Lead Azide
- **High (secondary) explosives**
  - TNT
  - PETN
  - Amonium Nitrate
- **Commercial explosives**
  - Amonium Nitrate based mixes

Principal Chemical Reaction

$$NH_4NO_3 \rightarrow N_2 + 2H_2O + 1/2\ O_2$$

plus hydrocarbon to react with the oxygen

Types of Explosives

- Nitroglycerin-based Explosives (Dynamites)
  - Gelatines, semigelatines = nitroglycerin + nitrocotton => gel structure (blasting gelatin)
  - Granular
  - Ammonia dynamite = nitroglycerin + ammonia nitrite
- Dry blasting agents (= liquid fuel + granular oxidizer)
  - ANFO = 94.5% ammonia nitrite (AN) + 5.5% diesel fuel
- Wet blasting agents
  - Slurries (water gels, 20% water) = collodial suspension of solid AN particles suspended in a liquid AN solution that is gelled (cross linking agent) + fuel oil, TNT, nitroglycerin
  - Emulsions = two-liquid phase of aqueous nitrates dispersed in fuel oil (emulsifying agent)
  - heavy ANFO = 50% ammonium nitrate emulsion + ANFO
- Permissible explosives
  = mixtures producing short-lived detonation flames => no ignition of methane or coal dust
  - $NH_4CL + NaNO_3 \Rightarrow N_2 + 2H_2O + 0.5\ O_2 + NaCl$
- Primer = explosive (ignited by an initiator) initiating an explosive which can't be initiated by an initiator = cartridge of dynamite
- Booster = placed where aditional power is needed = cartridge of dynamite

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Adding components for Ammonium Nitrate

Explosive	Oxydator	combustibles
Ammon-Gelit	Ammonium nitrate	gelatin dynamite
Donarit	Ammonium nitrate	Blasting oil, wood flour, coal
Anfo	Ammonium nitrate	Mineral oil
Slurry	Ammonium nitrate	Aluminium, mineral oil
Emulsified Blasting Agent	Ammonium nitrate	Mineral oil, emulsifier

Blasting

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Properties of Anfo

Density :	0,83	g/cm³
VOD:	2500-3500	m/s
Fume volume:	980	l/kg
specific Energy:	1 010	kJ/kg
oxygen balance:	-1.1	%

- not water resistant
- pneumatic chargeable
- delivered as prills
- needs booster for save detonation
- Applications:
  - Surface Mining
  - Large Scale Underground Stopes
  - Salt Mining

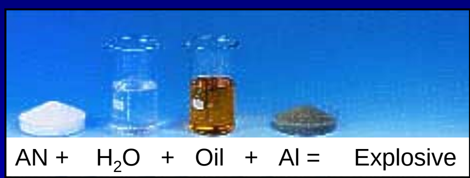
Properties of Gelatine Agents

Eurodyn:

Density :	1,5	g/cm^3
VOD:	2850-6500	m/s
Fume volume:	897	l/kg
specific Energy:	1 102	kJ/kg
oxygen balance:	+1.2	%

- water resistant up to 60°C
- delivered in cartridges
- Applications:
  - Surface Mining as booster
  - Road Heading (especially in cut)
  - Salt Mining as booster

Emulsified blasting agents



- **Components:**
  - oxidizing agent (Ammonium nitrate)
  - Water
  - combustible material (Mineral oil, paraffinic or micro crystalline wax)
  - Gas filled micro balls for regulating the density and for sensibility

Emulsion

Nobelit:

Density :	1,15-1,23	g/cm^3
VOD:	5700	m/s
Fume volume:	1058	l/kg
specific Energy:	730	kJ/kg
oxygen balance:	-9,4 to +3,6	%

- water resistant
- delivered pumpable or in cartridges
- Applications:
  - Surface Mining
  - Road Heading
  - Large Scale Underground Stoping

Acknowledgement: Dynamit Nobel Germany

Detonating Cord

- PETN core enclosed in various plastics and yarns
- VOD of detonating cord is 6400 m/sec
- Any number of charges can be hooked up
- Delays:
  surface detonating relays or
  down the hole delays (preferred)
- Not sensitive for extraneous electricity
  (impact & friction danger)
- Down lines of detonating cord can desensitise certain explosives due to shock
- Applications: Ignition of big hole blasting in surface mines
  Contour Holes in Road Heading

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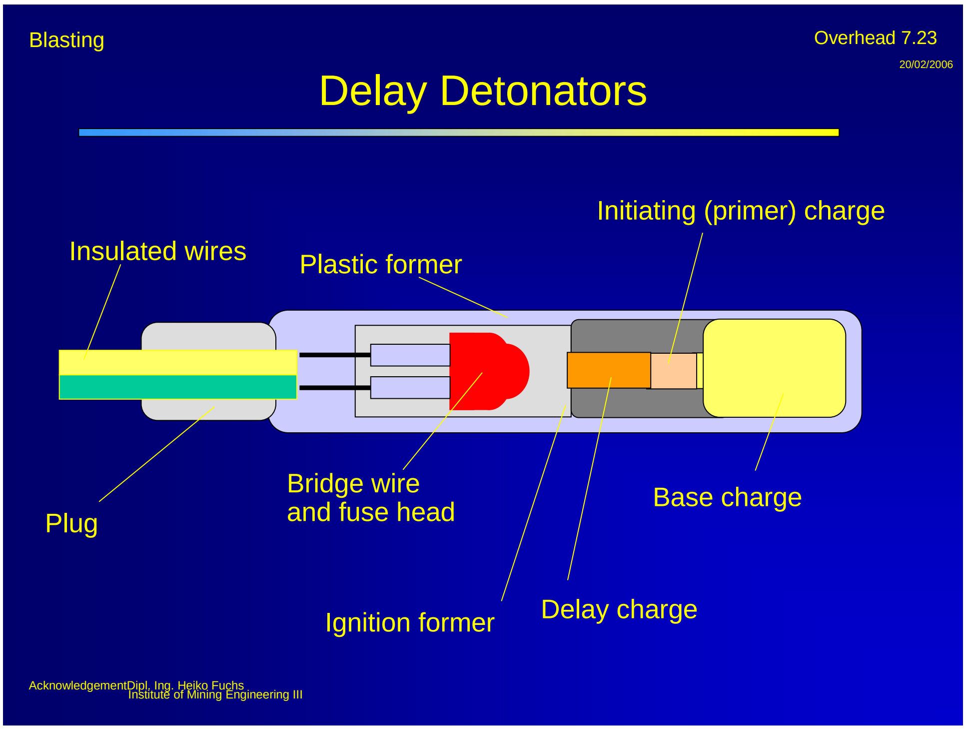
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Delay Detonators
Insulated wires
Plastic former
Initiating (primer) charge
Plug
Bridge wire
and fuse head
Base charge
Ignition former
Delay charge
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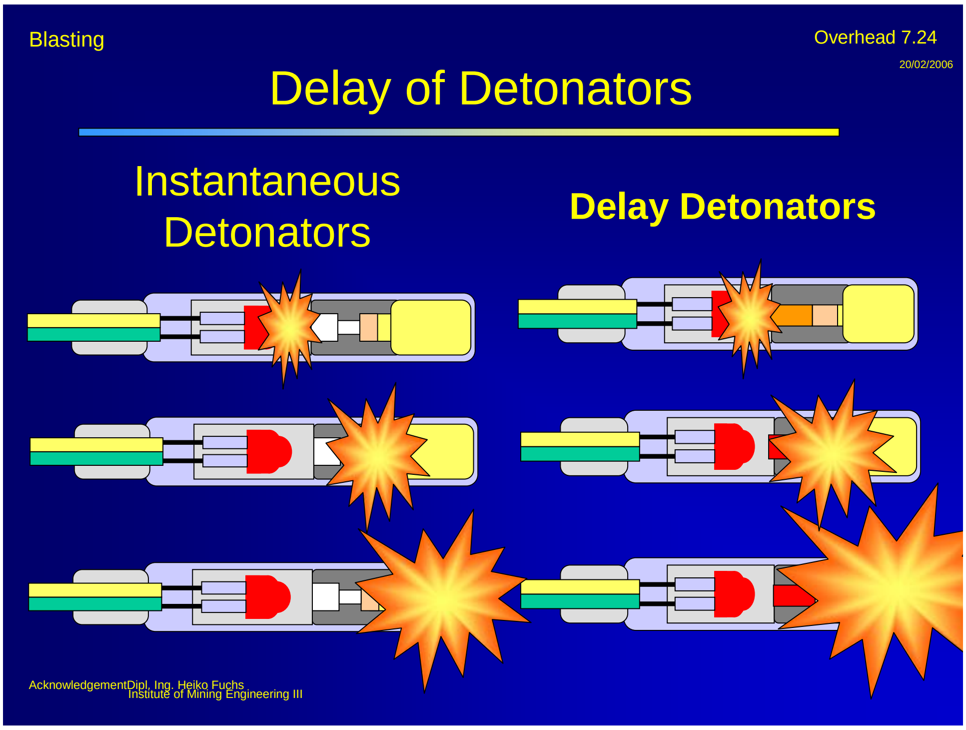
Blasting
Overhead 7.24
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Delay of Detonators
Instantaneous
Detonators
Delay Detonators
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Blasting

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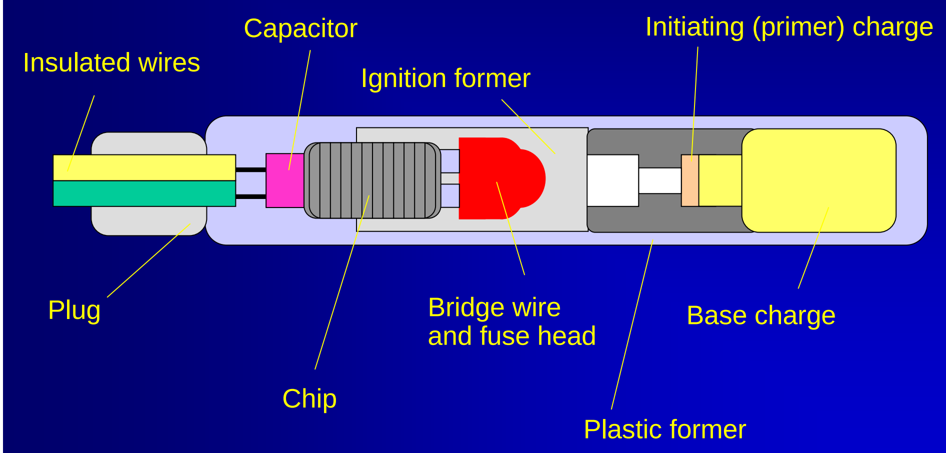
Electronic Detonator



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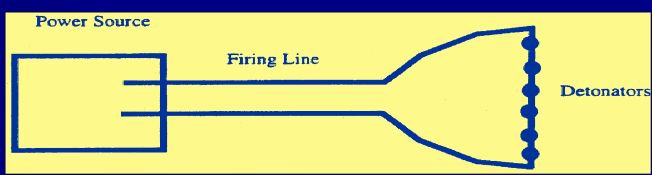
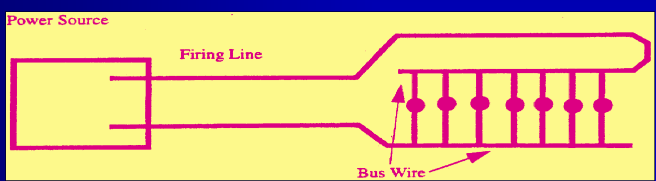
Connecting Circuits

Serial ignition circuit

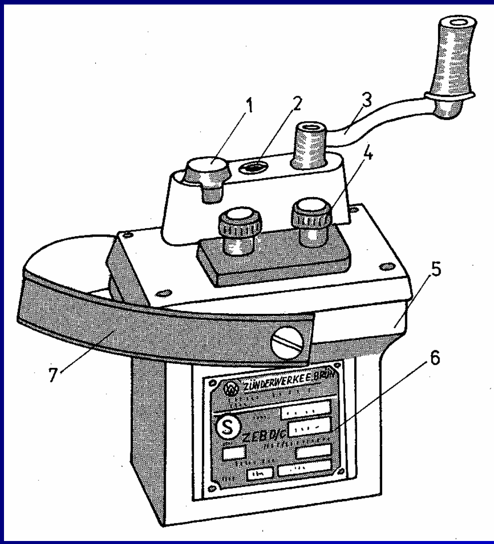


Parallel ignition circuit



Acknowledgement : C.E. Gregory,1984

Ignition Machine



Nonel System

- Shock tube with a layer of explosive material at inner surface
- Transmit a low pressure shock wave at 2000 m/sec
- Because detonation is sustained by very small quantity of reactive material, system is compatible with all grades of commercial explosives
- Many connectors exist to attach Nonel to other type system

Blasting

Non-Electric Shock-Tube Initiation Systems

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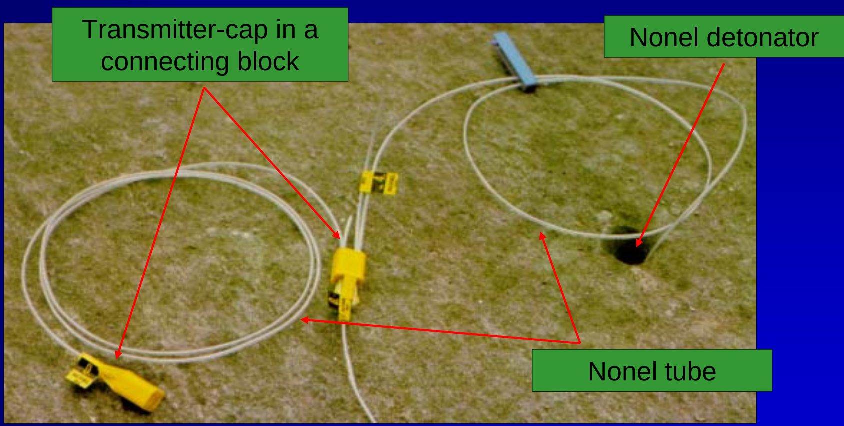

Acknowledgement : Nitro Nobel Group

Blasting

Nonel in Underground Mining

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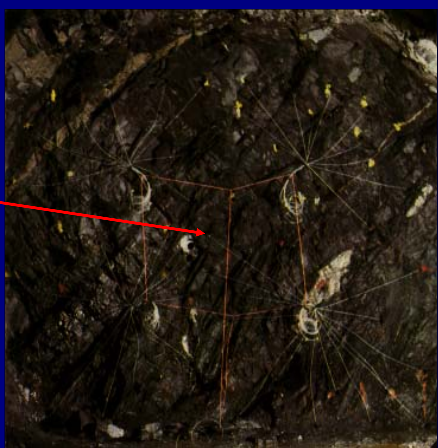
Look closely ....



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Nonel in Underground Mining

The result ....

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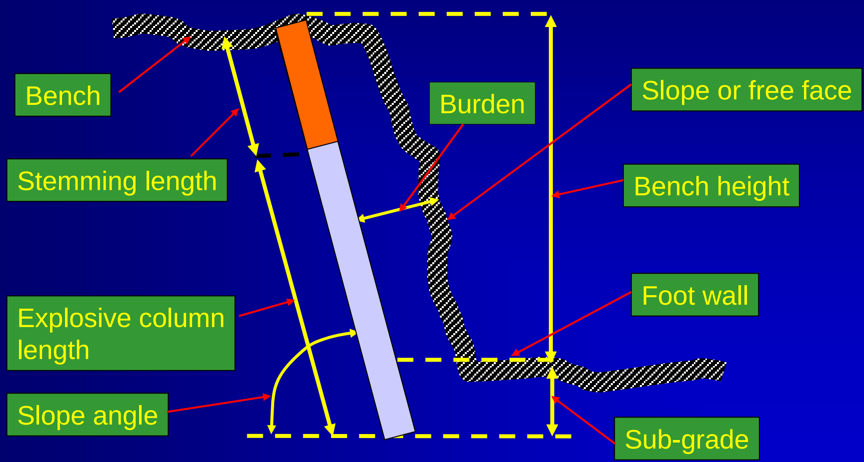
Borehole Geometry



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Blasting

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Delay Detonators in Surface Blasting

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Blasting

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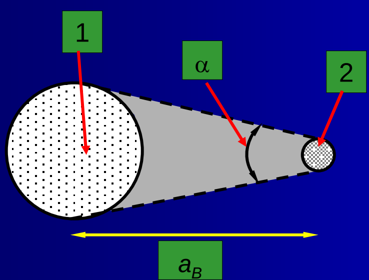
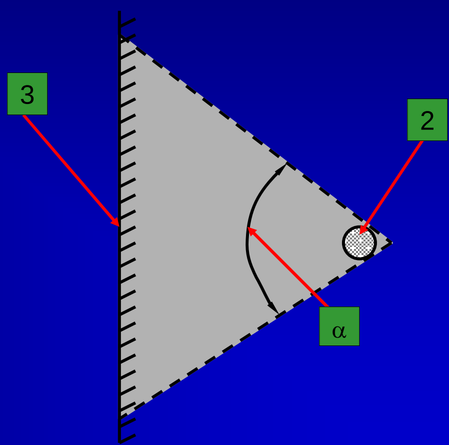
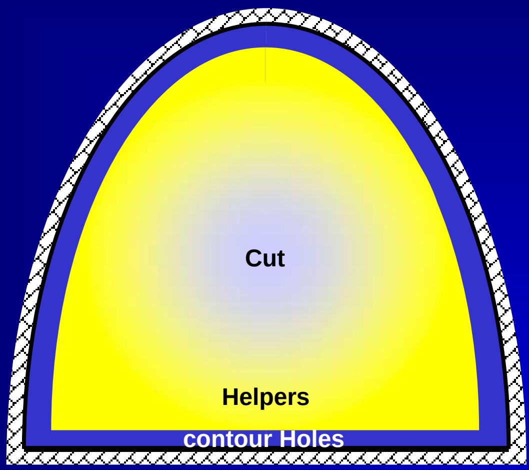
Effect of a Charge into the Direction of a Free Face

1 large diameter bore hole
2 blasting bore hole
3 free face
α blasting angle
a_B distance between bore holes

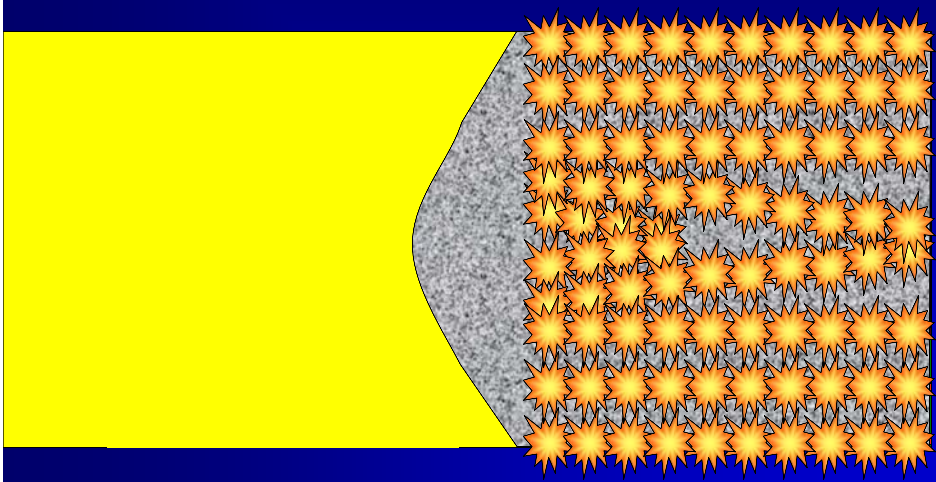




Blasting Bore Hole Geometry in Road Heading



Blasting with Delay Steps



Types of Cuts

- **Incline Cut**
  - Bore hole axis is slant to the development direction (axis of the development)
- **Parallel Cut**
  - Bore hole axis is parallel to the direction of the blasting bore holes (axis of the development)

Types of Incline Cuts

- Cone cut
- Wedge cut
- Fan cut

Blasting

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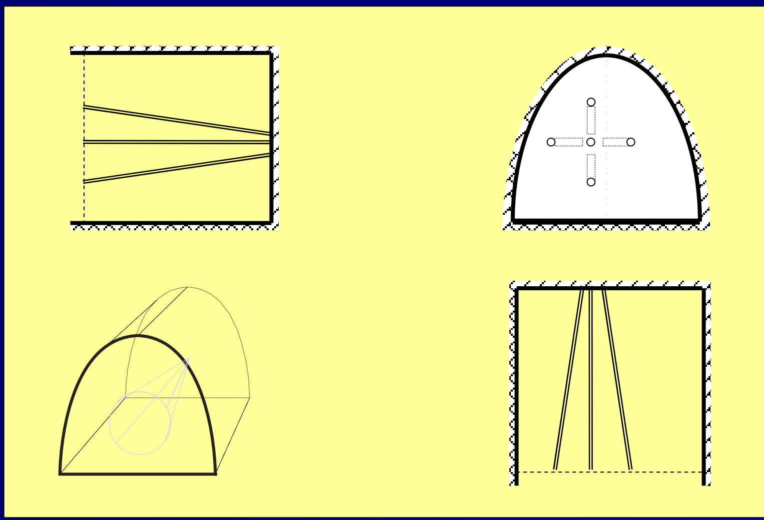
Cone Cut



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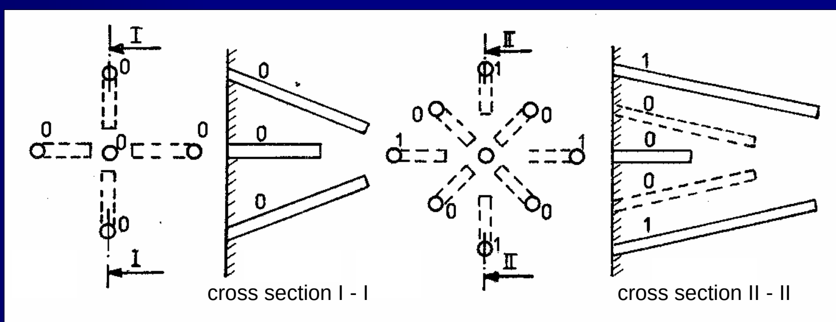
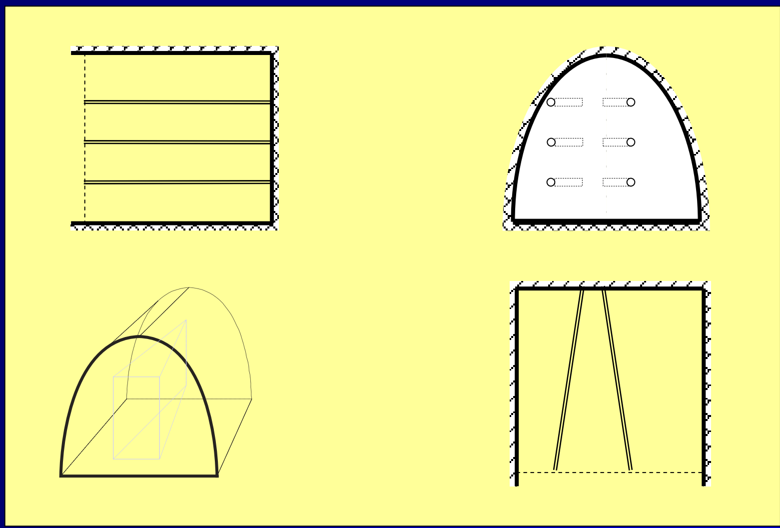
Types of Cone Cut



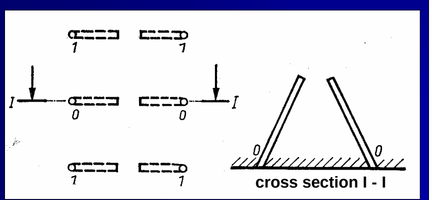
Simple cone cut

Split-level cone cut

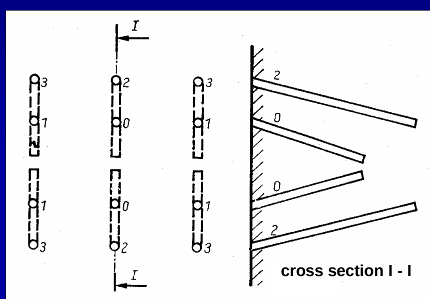
Wedge Cut



Types of Wedge Cuts



Simple wedge cut



Split-level wedge cut

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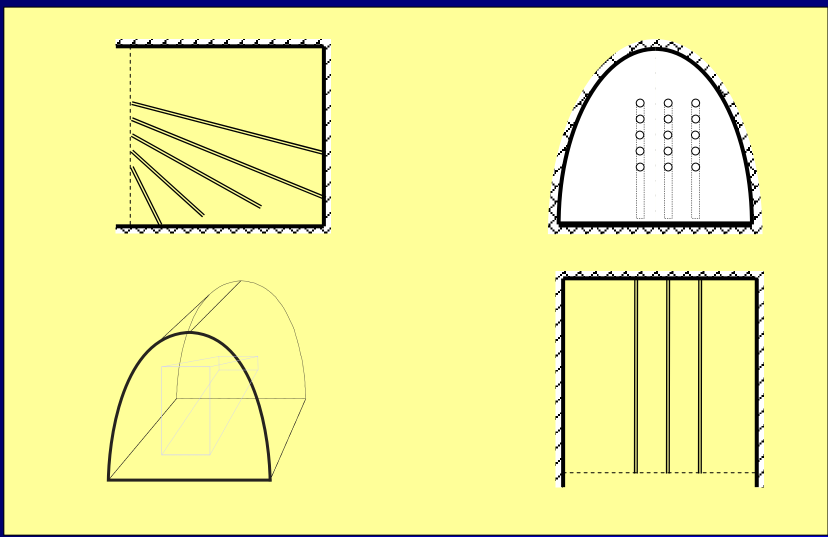
Fan Cut



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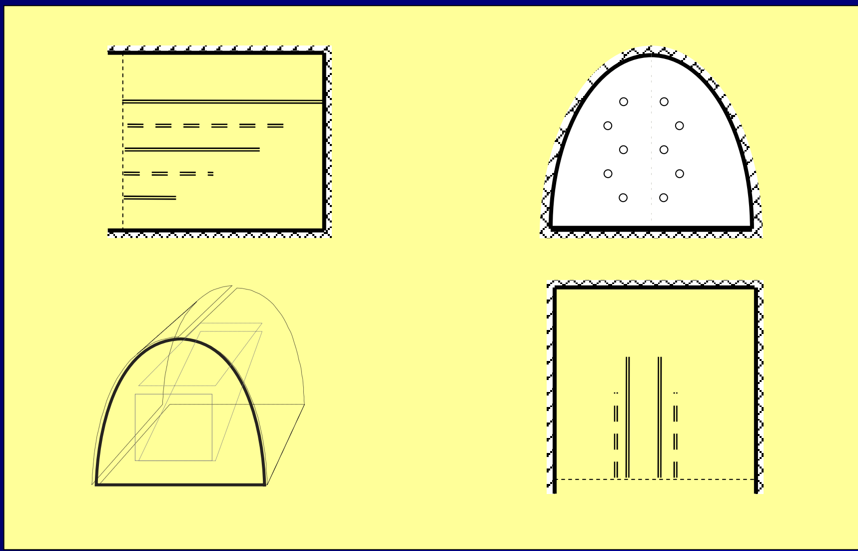
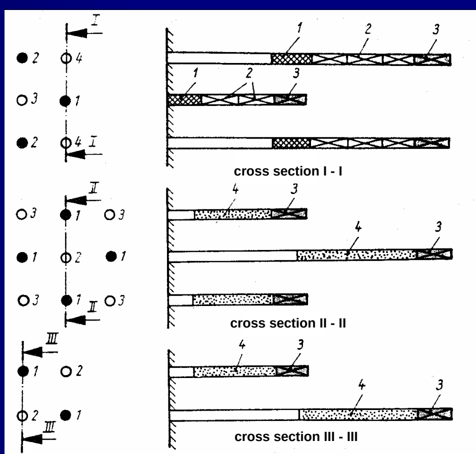
Types of Parallel Cuts

- **Parallel break-ins with out free face bore holes**
  - Split-level cut
  - Step-like cut
- **Parallel break-ins with free face bore holes**
  - Burn cut
  - Large diameter bore hole cut

Split-level Cut



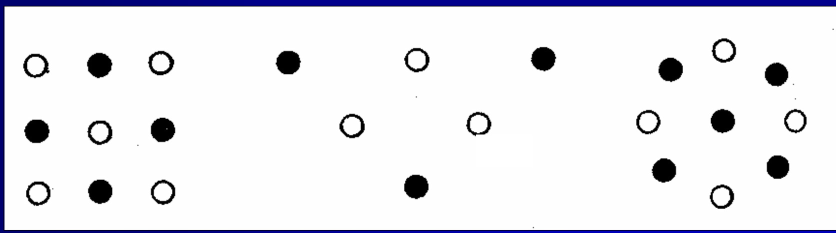
Step-like Cut



Acknowledgement: BBK I

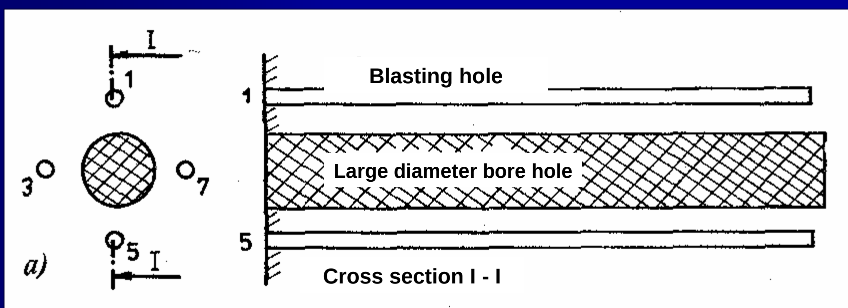
1 Stemming
2 Blasting cartridge
3 Primer
4 AN/FO
● 1-m- blasting hole
○ 2-m- blasting hole

Types of Burn Cuts



- bore hole is not charged
- Bore hole is charged

Large Diameter parallel Cuts



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Arrangement of Large Diameter Bore Holes

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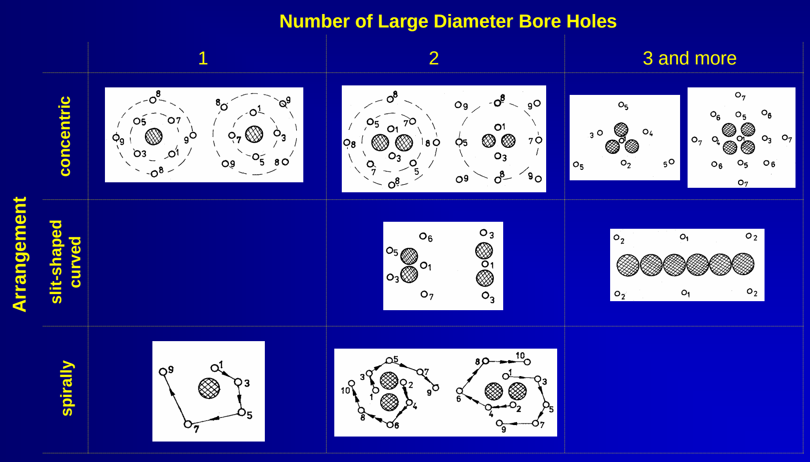

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Large Bore Hole Diameter and Depth of Pull

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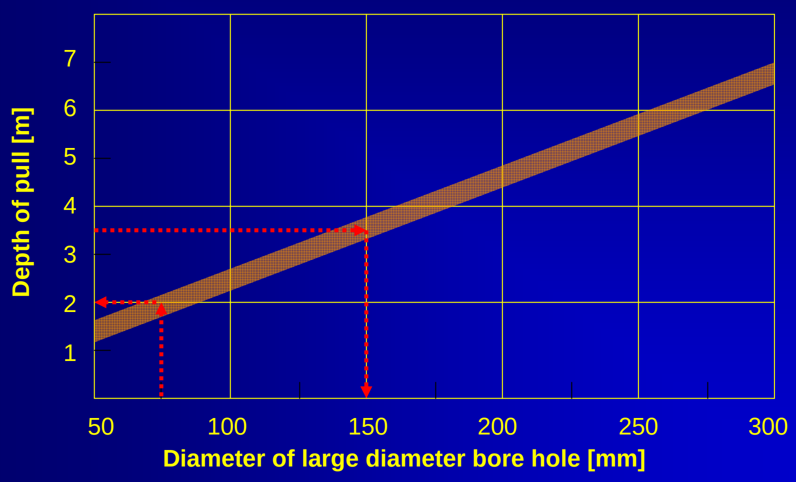
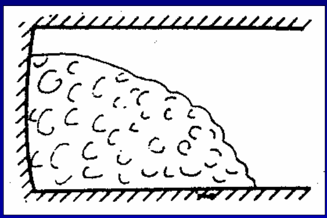


Length of Depth Pull in Underground Mining

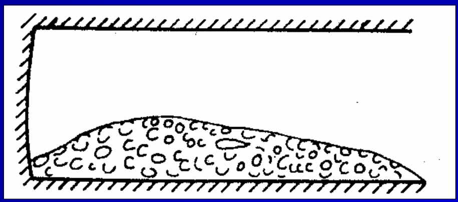
Iron Ore Mining	
• Development	1,5 to 3,0 m
• Raise development	1,0 to 2,0 m
• Shaft Sinking	2,0 to 4,5 m
Rock salt and pot ash mining	
• Development and mining (Room and pillar mining)	4,0 to 8,0 m (mostly 5,40 m and 6,50 m)
Hard coal mining	
• Development	2,5 to 4,0 m
• Seam mining	1,5 to 3,0 m
Tunnelling	
• Development	3,0 to 4,0 m

Loading with Different Equipment

For front end loading



For scraper loading



Blasting

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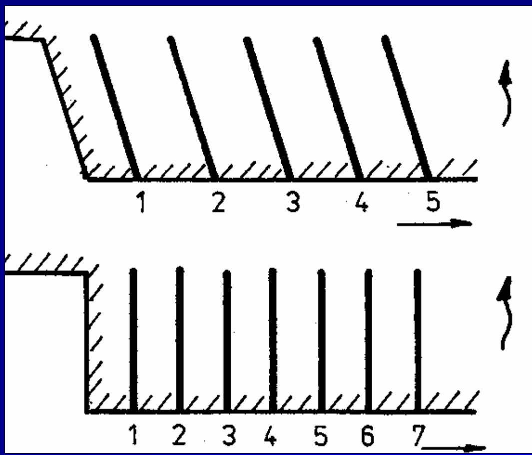
Blasting Holes in Row

Inclined to the face

Strait to the face



Advance direction

Direction of working

Blasting

Blasting Pattern in Cut and Fill Stoping

Overhead 7.54

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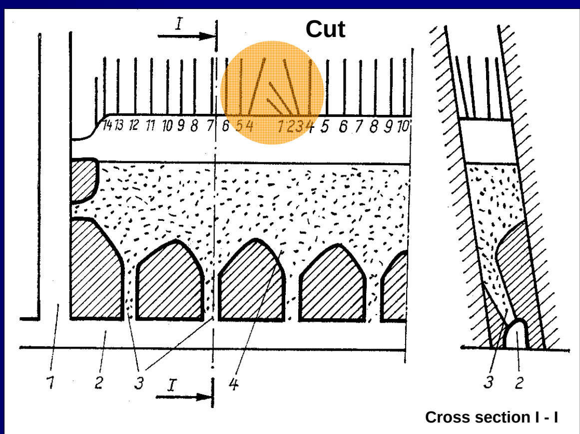


1 Raise

2 Base Development

3 Chute

4 Muck

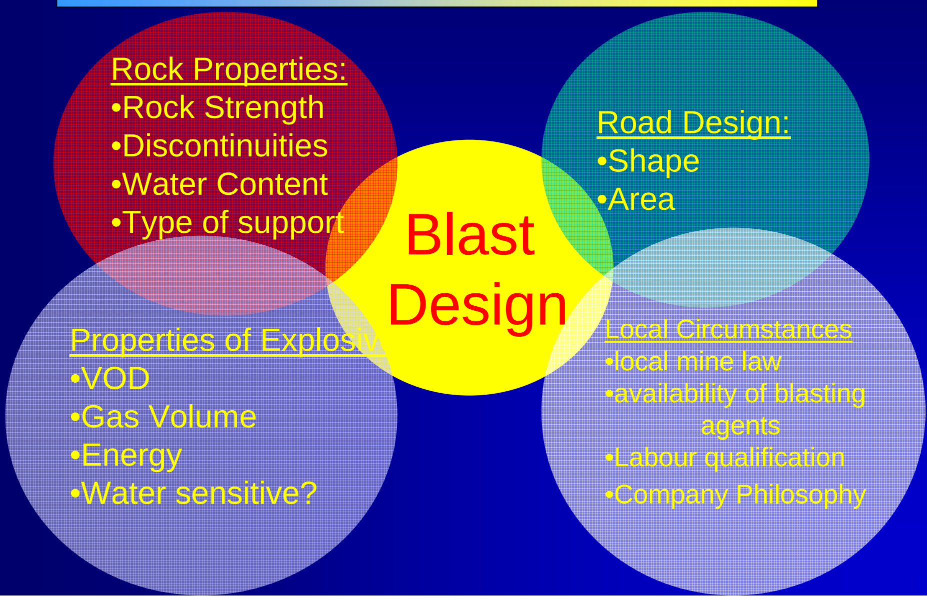
Principles of Blast Design

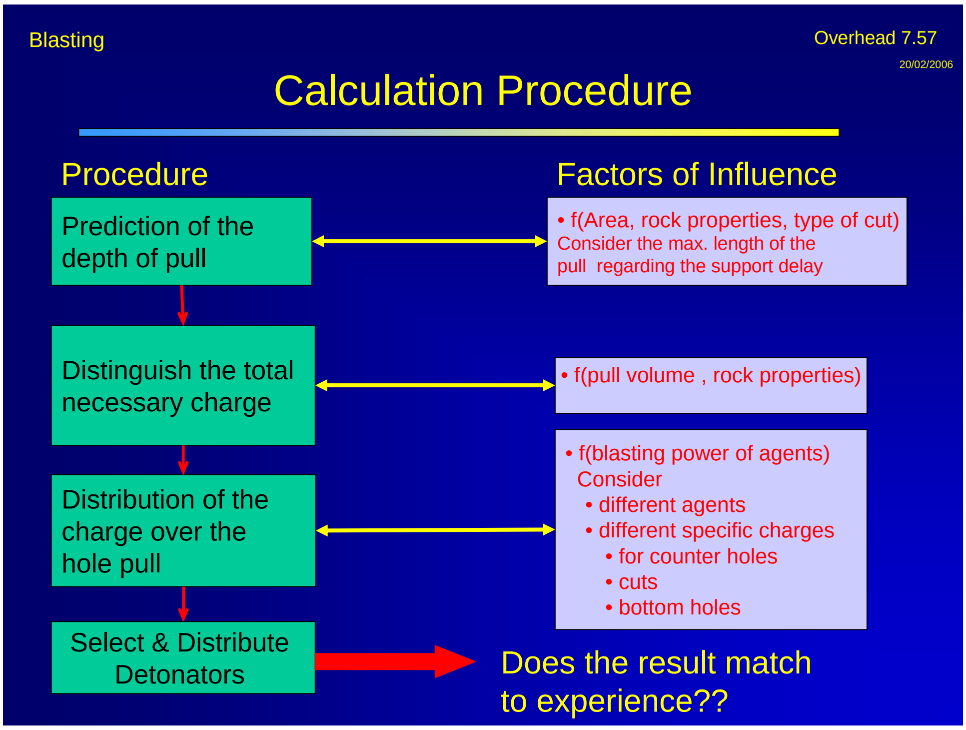
- Design of blasting patterns and the calculation of the required charge for each pull in underground mining is mainly based on the experience of blasting engineers.

- There are as many methods of calculating the required charge, as there are publications from experts in the literature.

- The following way of predicting the necessary charge of a pull does only give a rough overview how pulls may be calculated.
- This calculation may not be sufficient in all cases.

Parameters Influencing Blast Design




Blasting
Overhead 7.57
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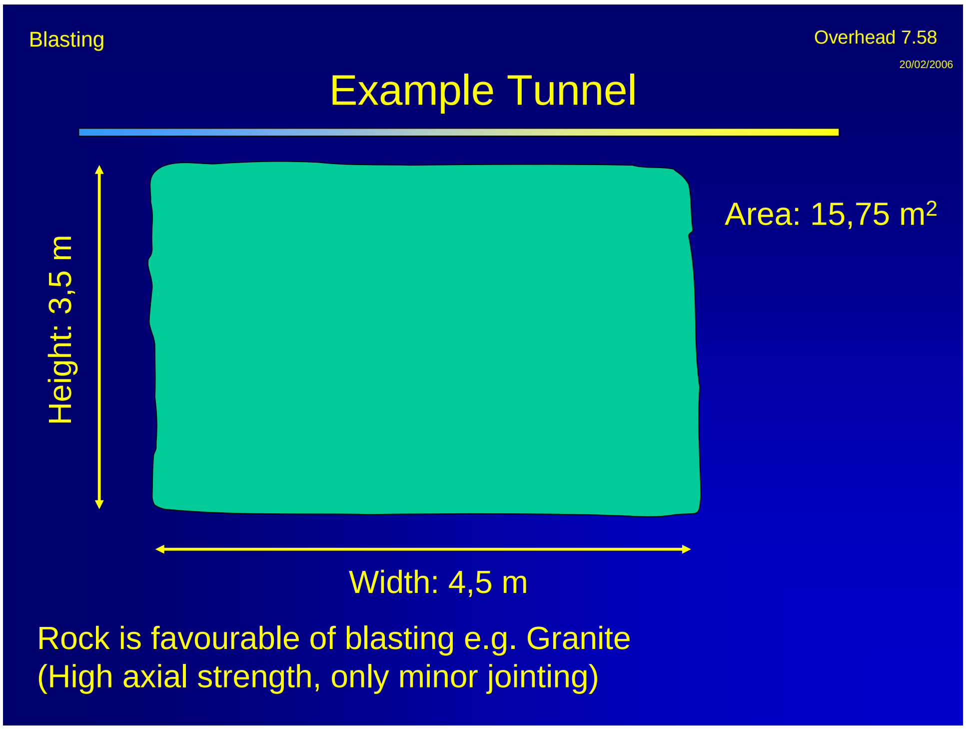
Calculation Procedure
Procedure
Factors of Influence
Prediction of the depth of pull
• f(Area, rock properties, type of cut)
Consider the max. length of the pull regarding the support delay
Distinguish the total necessary charge
• f(pull volume , rock properties)
Distribution of the charge over the hole pull
• f(blasting power of agents)
Consider
• different agents
• different specific charges
• for counter holes
• cuts
• bottom holes
Select & Distribute Detonators
Does the result match to experience??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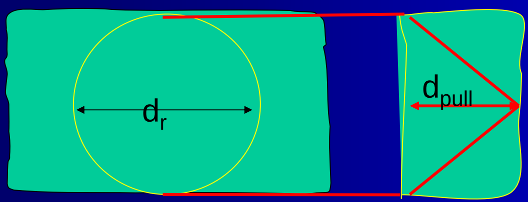
Example Tunnel
Height: 3,5 m
Area: 15,75 m²
Width: 4,5 m
Rock is favourable of blasting e.g. Granite
(High axial strength, only minor jointing)

Depth of Pull & Cut 1

- The Depth of pull is limited by:
  - length of drill steel
  - geometry of carriage regarding type of cut and road width
- Depth of pull in hard rock conditions is seldom more than 4 m
- The cut needs to be 0.2- 0.4 m longer than the depth of pull (over drilling)
- Calculation of the depth of pull (rule of thumb):



$$d_{pull} = d_r / 2$$

d_{pull} = depth of pull
d_r = diameter road circle (max. of height or width)

Depth of Pull & Cut 2

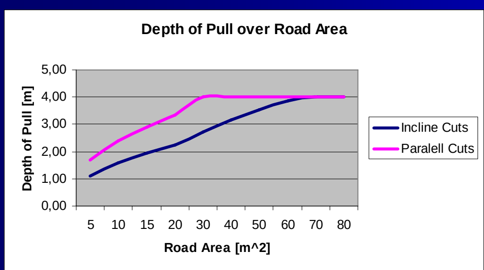
Regarding the type of cuts the following empirical calculations have established:
(for medium favourable rock)

- for inclined cuts: (e.g. cone, wedge, fan cuts)

$$d_{pull} = 0{,}5 \cdot \sqrt{A_{pull}}$$

- for parallel cuts:

$$d_{pull} = 0{,}75 \cdot \sqrt{A_{pull}}$$



Example:
usage of a parallel cut:

$$d_{pull} = 0{,}75 \cdot \sqrt{15{,}75 m^2}$$
$$d_{pull} \approx 3m$$

$$V_{pull} = A_{road} \cdot d_{pull} = 15{,}75m^2 \cdot 3m = 47{,}25m^3$$

Total necessary Charge 1

The necessary charge can be estimated either by readings from experience based charts/tables or by empirical formulas.
Attention: Formulas are often only in a certain range and under special conditions suitable tools.

Rough overview on specific charges:

powder factor (q) given in kilogram per volume of Pull

Type of Rock	Area up to: 6m²	10m²	40m²	Properties of the Blasting Agent
Soft: Gypsum, Clay, Marl	1,5 to 0,8	1,3 to 0,6	1 to 0,3	low VOD high fume Volume
Medium: Sanstone, Lime, Schist	3 to 2	2,7 to 2	2,5 to 1,5	for cut and counter holes high VOD in the bottom holes high fume Volume
Hard: Lime, Dolomite, Granite	4 to 3	3,5 to 2,5	3 to 1,7	high VOD
Very Hard: Granite, Quarz, Gneiss	4,5 to 3,5	4 to 3	3 to 2	high VOD

Example:
q estimated from table:
2 to 2,5 kg/m³

Total necessary Charge 2

One empirical method to calculated the required powder factor:

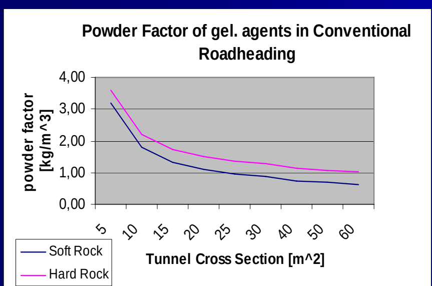
$$q_{gel} = \frac{14}{A_r} + v_{rock}$$

v_{rock}= spec. value for different rock types

v_{rock}= 0,4 soft rock

v_{rock}= 0,8 hard rock

q_{gel}= gelatinous blasting agent based powder factor



to adjust q_{gel} to q an experience based performance factor f_{bl} for each blasting agent is required:

Anfo:	1,5- 1,6
Emulsion:	1,2- 1,3
gelatinous Agents:	1

$$q_{gel} = \frac{14}{15{,}75} + 0{,}8 \approx 1{,}7 kg/m^3$$

Distribution of Charge 1

- number of blasting holes:
  - as a rule of thumb the <u>cut</u> needs 6-7 kg/m^3 and the holes should be loaded as least up to 3/4 of the length of the hole

Example:
- parallel cut with 4 large drill holes:

number of charged holes in the cut: 13

$$A_{cut} = \left[\frac{width_{cut}}{\sqrt{2}}\right]^2 = 1{,}125m^2$$

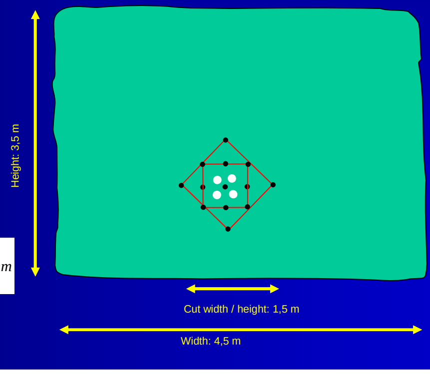
$$V_{cut} = A_{cut} \cdot d_{pull} \approx 3{,}4m^3$$

$$Q_{gelcut} = V_{cut} \cdot 7kg/m^3 = 23{,}8kg$$

Required hole diameter:

$$d_{charge} = \sqrt{\left(\frac{Q_{cut}}{\rho_{agent} \cdot n_{hcut} \cdot \pi \cdot (d_{pull} + 20cm) \cdot 3/16}\right)} = 28{,}5mm$$

→ Select 28 mm cartridge & a 30 mm drill bit



Distribution of Charge 2

Distribution of Counter Holes:

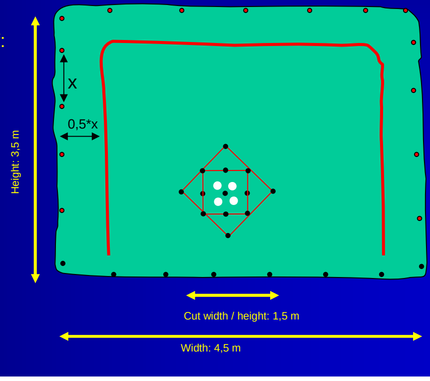
- in good rock conditions the spacing x between the holes can reach up to 70 cm
- the burden of counter holes is estimated by 0,5 times the spacing
- floor holes should be charged at least up to 0,5 m

Example:

Charge of counter holes side wall / roof:

$$Q_{counterh} = 0{,}1\frac{kg}{m} \cdot d_{pull} \cdot n_{counterholes} = 4{,}5kg$$

$$Q_{floorholes} = n_{floorholes} \cdot (d_{pull} - 0{,}5m) \cdot \rho_{agent} \cdot \pi \left(\frac{d_{cartridge}}{2}\right)^2 \approx 14{,}7kg$$



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Distribution of Charge 3

Total quantity of blasting agent Q_{gel}:

$$Q_{gelpull} = q_{gel} \cdot V_{pull} = 80.3kg$$

Charge for mass breaking:

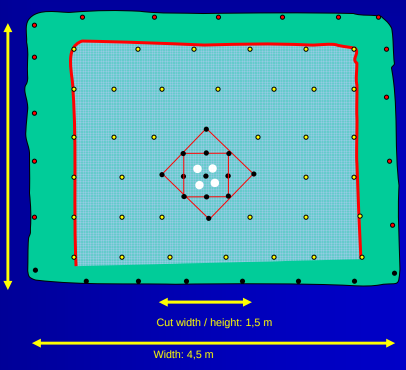
$$Q_{gelmass} = Q_{geltotal} - Q_{cut} - Q_{counterh} - Q_{floorholes} = 37{,}3kg$$

- in the case of a different blasting agent: (e.g. in this case emulsion)

$$Q_{mass} = Q_{gelmass} \cdot f_{bl} = 44{,}8kg$$

- mass holes loaded up to 2/3 of length

$$n_{hmass} = \frac{Q_{mass}}{\rho_{agent} \cdot \pi \cdot \left(\frac{d_{cartridge}}{2}\right)^2 \cdot d_{pull} \cdot 2/3} \approx 36$$



Blasting

Overhead 7.66

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Select and Distribute Detonators